Status of the JSNS^2 and JSNS^2-II experiments

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Weak Interactions and Neutrinos
(WIN2021, Jun 7-12, 2021)

J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source

Collaboration meeting @ J-PARC (2020/Feb)

JAEA
KEK
Kitasato
Kyoto Sangyo
Osaka
Tohoku

Soongsil
Dongshin
GIST
Seoyeong
Chonnam National
KyungHee
Chonbuk National
Kyungpook National
Sungkyunkwan
Seoul National of sci and tech

Sussex

Alabama
BNL
Florida
Michigan
Utah

JSNS^2 collaboration (65 collaborators)

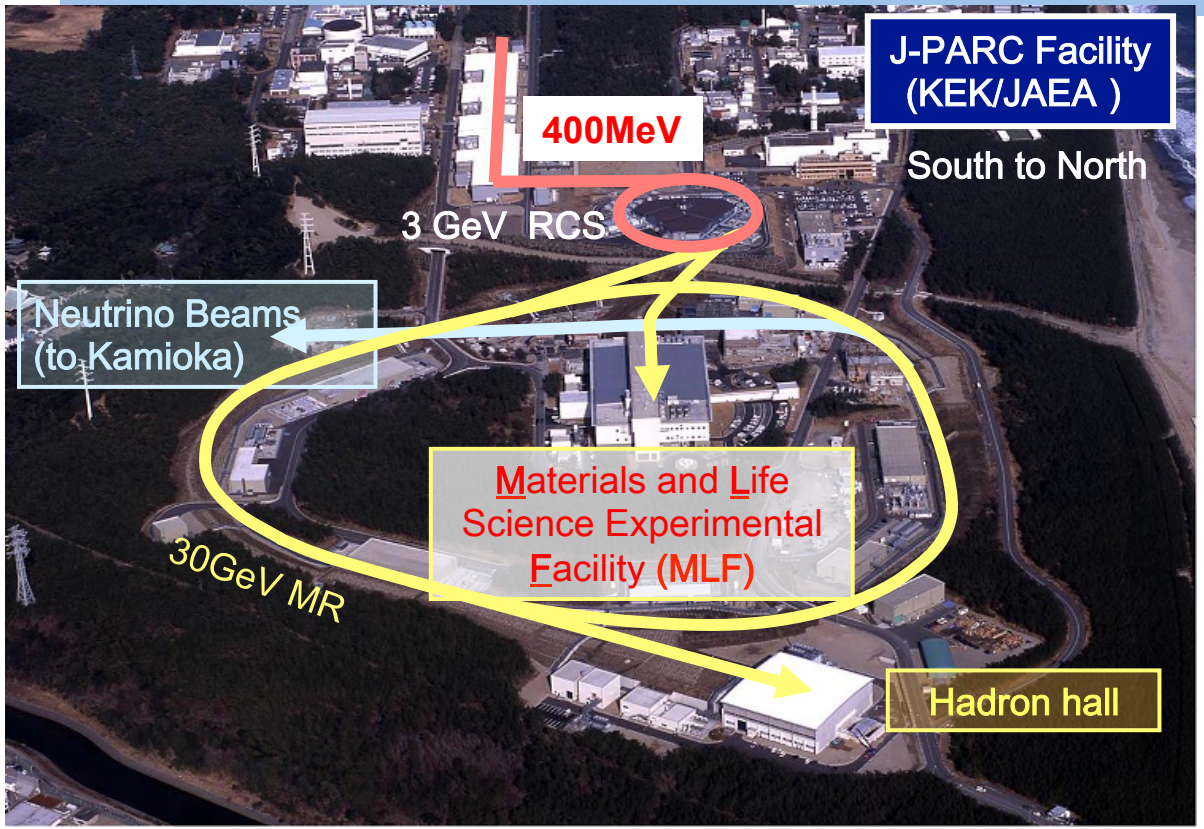
- 6 Japanese institutions (31members)
- 10 Korean institutions (25 members)
- 1 UK institution (1 member)
- 5 US institutions (8 members)

Indication of a sterile neutrino ($\Delta m^2 \sim 1 eV^2$)

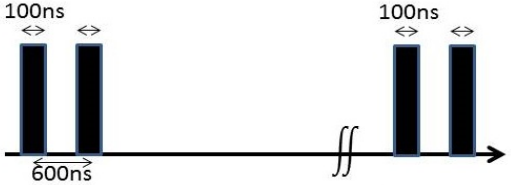
Experiments	Neutrino source	signal	significance	E(MeV), L(m)
LSND	μ Deacy-At-Rest	$\overline{\nu}_\mu \rightarrow \overline{\nu}_e$	3.8 σ	40, 30
MiniBooNE	π Decay-In-Flight	$\nu_\mu \rightarrow \nu_e$	4.5 σ	800, 600
		$\overline{\nu}_\mu \rightarrow \overline{\nu}_e$	2.8 σ	
		combined	4.8 σ	
	arXiv:1805.12028	+ LSND	6.1 σ	
Ga (calibration)	e capture	$\nu_e \rightarrow \nu_x$	2.7 σ	<3, 10
Reactors	Beta decay	$\overline{\nu}_e \rightarrow \overline{\nu}_x$	3.0 σ	1-8, 10-100

- Excess or deficit do really exist?
- Note: JSNS^2 uses the same neutrino source (μ), target (H) and detection principle (IBD) as the LSND → even if this is not due to the oscillation, we can catch this directly

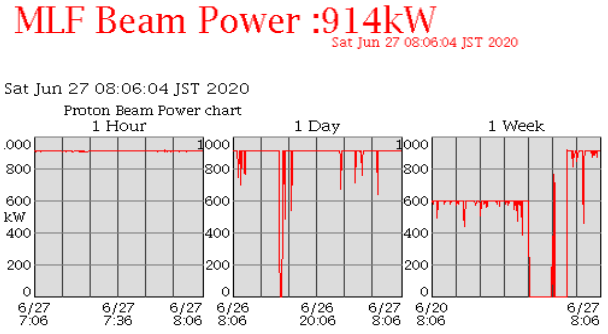
Bird's eye photo of the J-PARC



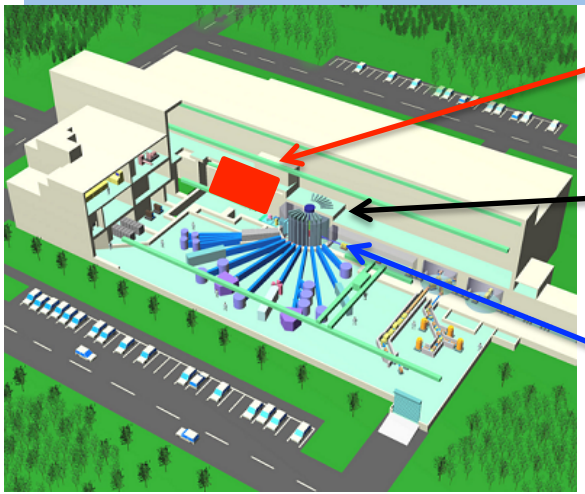
- **25 Hz, 1 MW (design)**
- **Two-bunch structure**
- **short-pulsed beam**



It is running with <u>0.74 MW</u> now.
0.91 MW beam was utilized for users from Jun-25 to 27 in 2020.



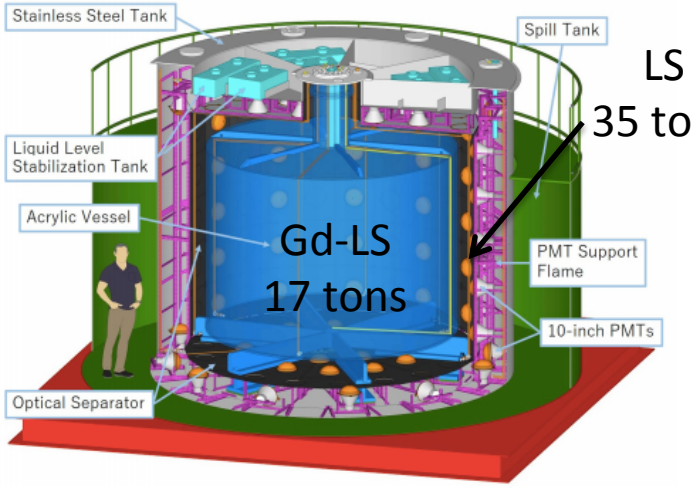
J-PARC MLF : one of the world best environments



Detector @ 3rd floor
(24m from target)

Hg target = Neutron
and Neutrino source

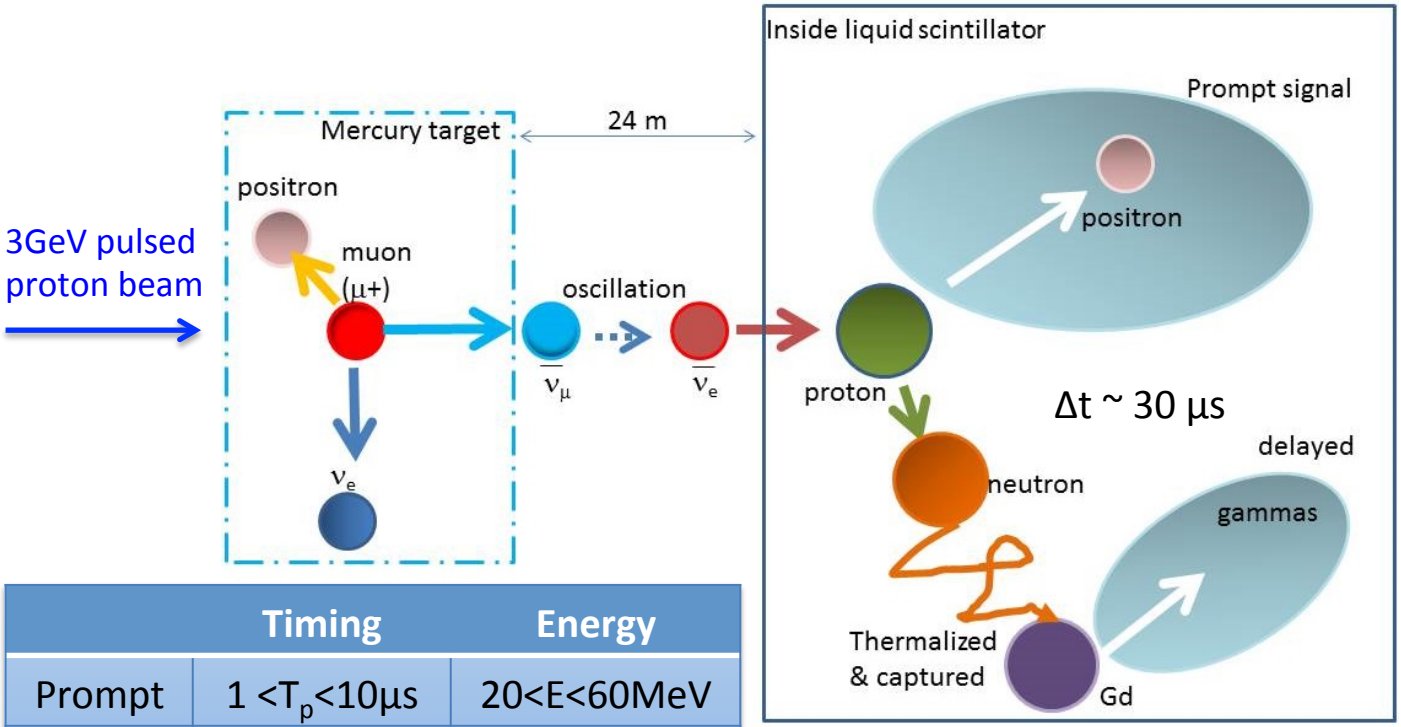
3GeV pulsed
proton beam



- 1st data taking : 2020/June/5 − 15 (10 days)
- 2nd data taking : 2021/January/12 − end of June (6 months)
- We are taking data now

- 52t (Gd-loaded + unloaded) liquid scintillator detector
- 4.6m diameter x 4.0m height
- 120 10” PMTs

Production / Detection



	Timing	Energy
Prompt	$1 < T_p < 10\mu s$	$20 < E < 60 MeV$
Delayed	$T_p < T_d < 100\mu s$	$7 < E < 12 MeV$

Most of them are same as the LSND.
→ Direct ultimate tests for LSND.

But use much better beam and Gd loaded LS.
→ Much better S/N
→ Much better systematics

Detector operation cycle

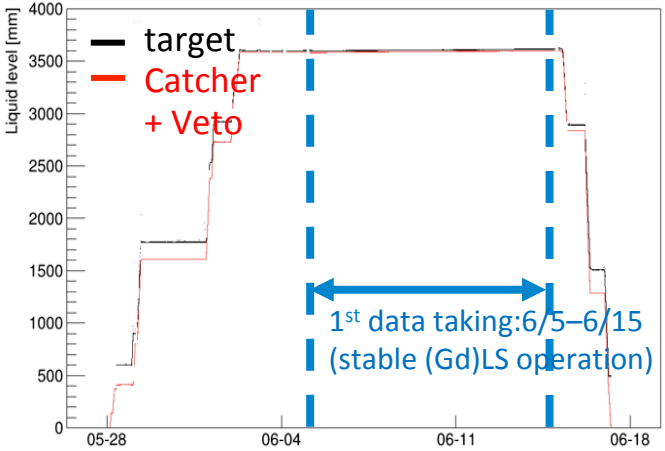
- MLF 3rd floor is the maintenance area for the mercury target and beam equipment. Thus, we need to bring in and out the detector during summer beam shutdown every year (4 months).
- I.e. : we have to fill in and extract out (Gd)LS during short time also.

① Move the detector from detector assembly building (HENDEL) to MLF
② Scintillator filling in MLF 1st floor **within 10 days**
③ Data taking in MLF 3rd floor **(1st and 2nd physics run)**
④ Scintillator extraction again in MLF 1st floor **within 10 days again.**
⑤ Move the detector to HENDEL (temporal storage area)

- Note that JSNS^2 have **already filled the scintillator two times** and **extracted the scintillator one time**.

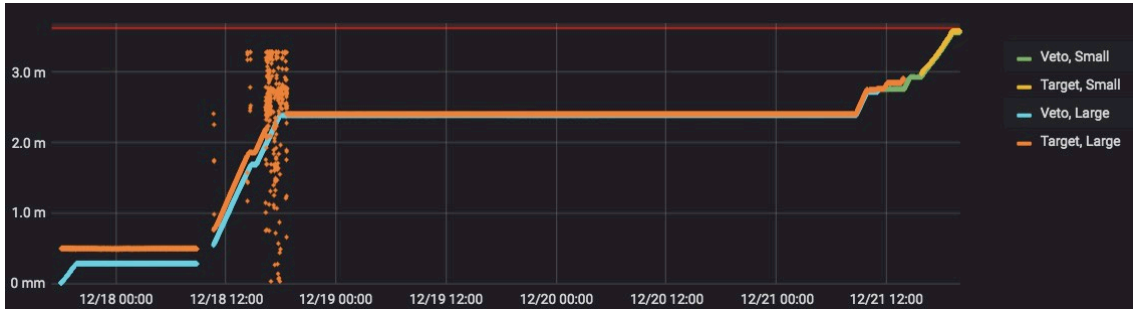
Move detector to MLF

Setup for filling



June, 2020

Detector on the MLF



Scintillator filling (second time), December, 2020

Beam power / POT

Average Beam power: 600 kw (2020) ➔ 740kW (2021/April -)

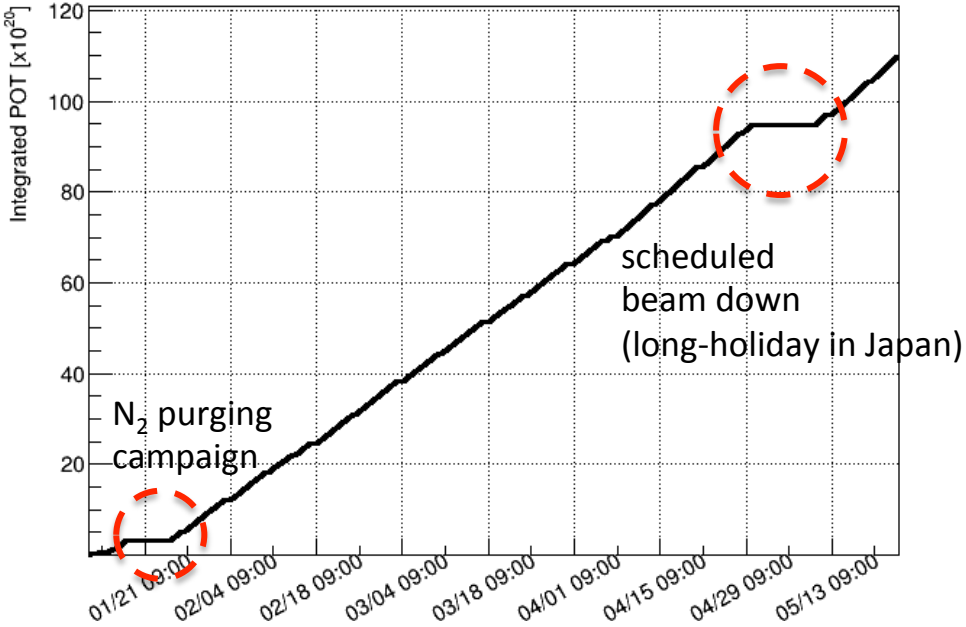
8.46 x 10^{20} POT for the 1st physics run

- 0.8% of approved POT (by J-PARC PAC)
- The detector was working well, and JSNS^2 shows strong potential from the next physics run.

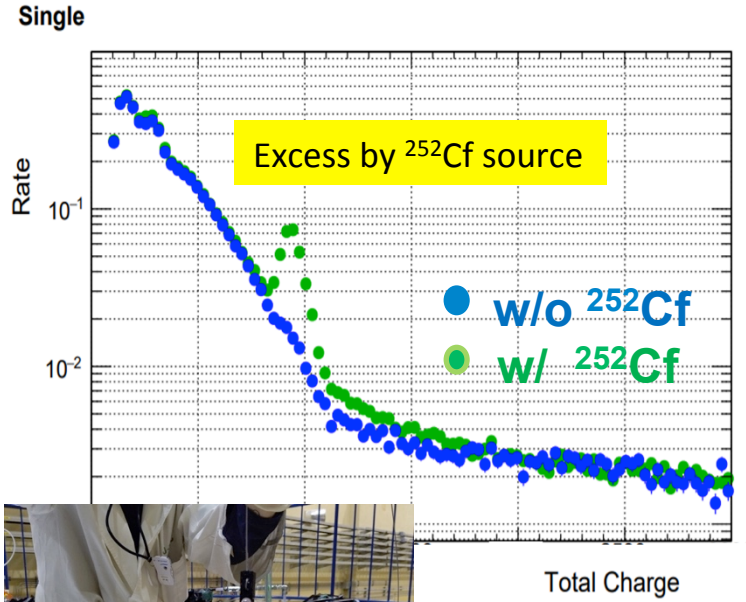
Have been taken more than 1.0 x 10^{22} POT (2021/May)

- 2nd physics run is running.
- Have cross-checked the 1st physics run result.
- Implemented efficient sterile neutrino trigger.
- **DAQ efficiency is very good : > 96 %**
- Analysis is on-going.

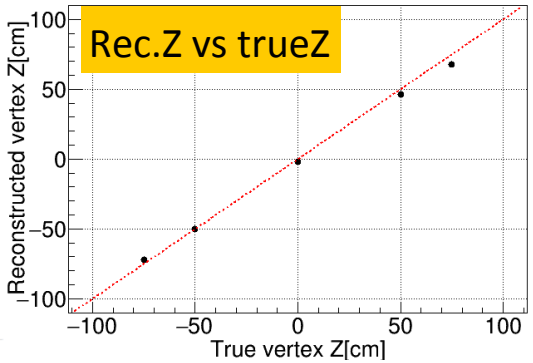
Acquired POT

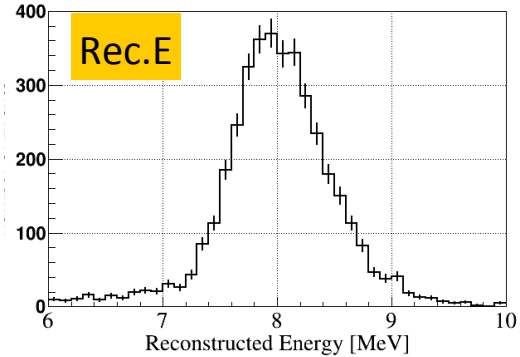


^{252}Cf calibration data



- Can see clear excess due to neutron capture on Gd.
- Detector is working well.





Cf	E Resolution	Vtx Resolution
data	5.1 ± 0.1 %	92 ± 3 mm
MC	5.3 ± 0.1 %	78 ± 2 mm

of expected events (1MW × 3 years×1 detector (17 tons))

Signal	$sin^2 2\theta = 3.0 \times 10^{-3}$ $\Delta m^2 = 2.5eV^2$ (Best fit values of MLF)	87
	$sin^2 2\theta = 3.0 \times 10^{-3}$ $\Delta m^2 = 1.2eV^2$ (Best fit values of LSND)	62
background	$\overline{\nu}_e$ from μ^-	43
	$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$	3
	beam-associated fast n	≤ 2
	Cosmic-induced fast n	negligible
	Total accidental events	20

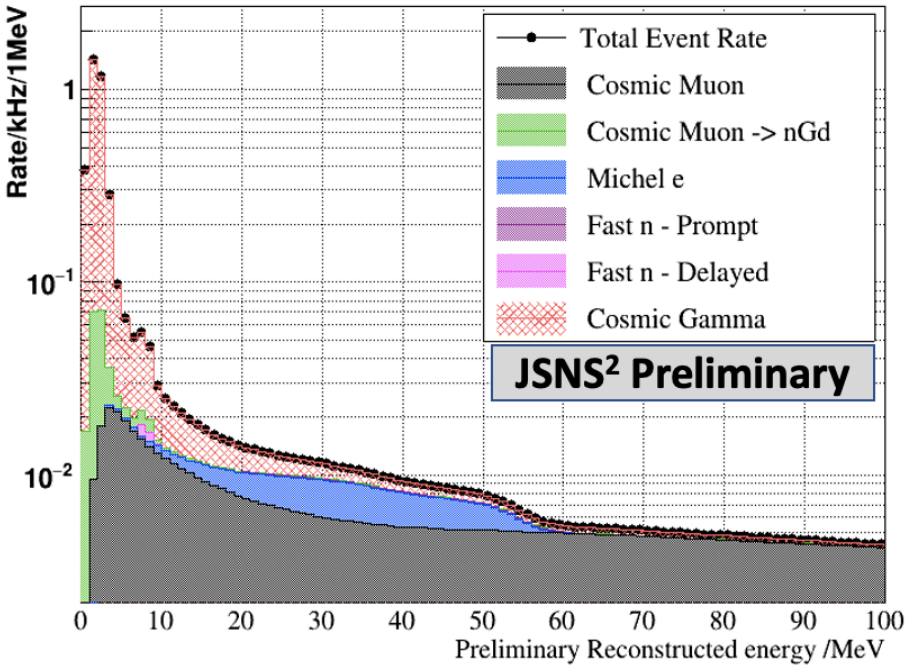
From the JSNS^2 TDR (arXiv:1705.08629)

We are investigating the backgrounds now.

Accidental BKG is calculated by;R acc = SR_{prompt} x SR_{delay} x D_{VTX} x N_{spill}

- SR_{prompt}, SR_{delay} are probability of accidental BKG for prompt and delayed.
- D_{VTX} ; BKG rejection factor of **50**.
- N_{spill}(#spills / years) = 4.5 x 10^8

Data w/o beam (cosmic ray induced BKG)

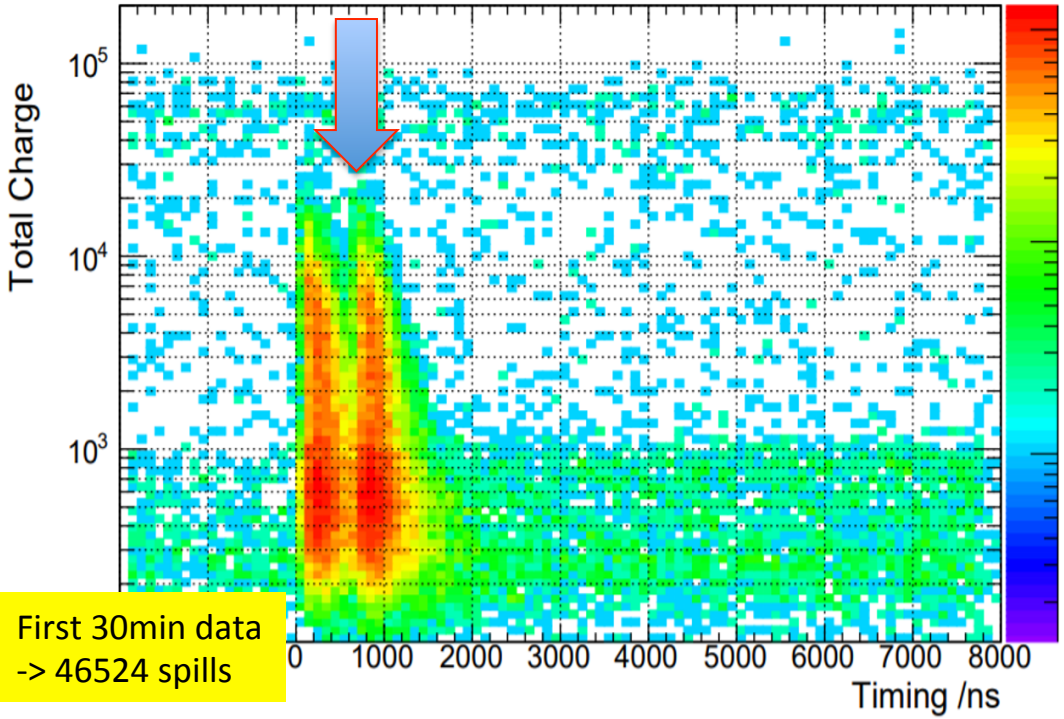


N.B.) Uncertainties for all components are 20% level.

- J-PARC has a day for the beam maintenance / week.
- Left plot shows the preliminary plots for the background components taken by self-trigger.
  - Cosmic ray muon : ~2.4kHz (all energy range. Including >100MeV)
  - Michel e : ~85Hz (20-60MeV)
  - Fast neutrons: ~3.6Hz (20-60MeV)
  - **Cosmic gamma: ~58Hz. (20-60MeV)**
  - **Cosmic gamma: ~100Hz (7-12MeV)**
  - these numbers have no fiducial volume cuts. BKG in the Catcher region are included in addition to target region. (target 20m^3 vs catcher 12.2m^3))
  - fast neutrons and gammas rays are induced by cosmic muons)
- Time window to select IBD is powerful to reject these. (9 us = ~10^{-5} reduction for IBD prompt, 100 us = 10^{-4} reduction for IBD delayed)

Background activities around beam timing

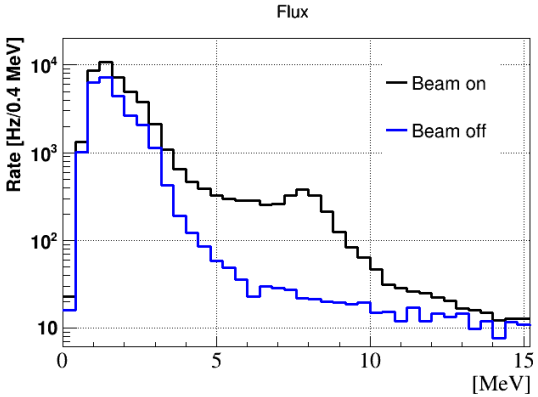
On-Beam (Two bunches)



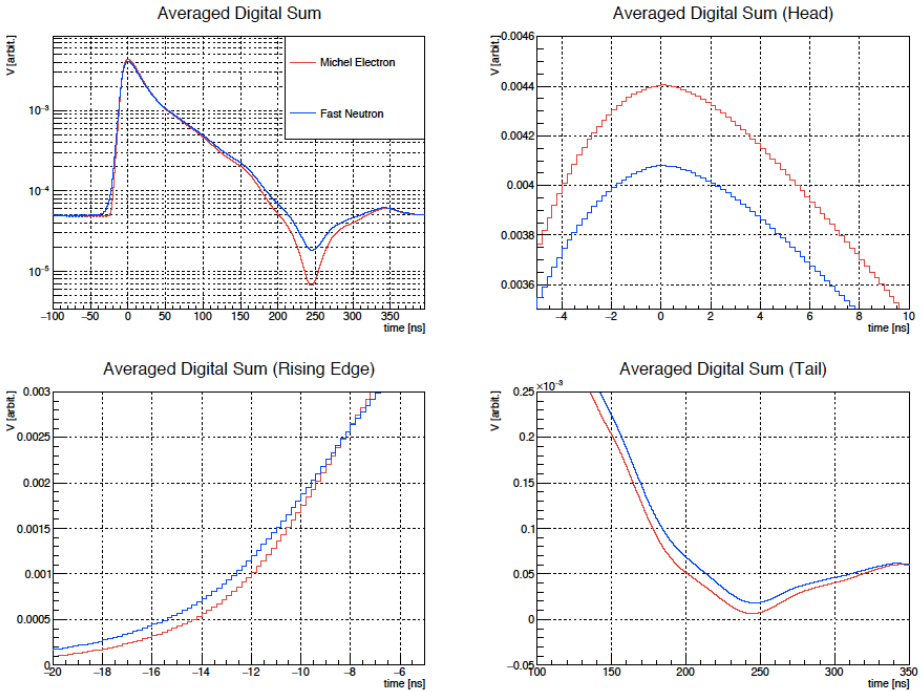
First 30min data
-> 46524 spills

IBD Prompt region
(cosmic ray related BKG)
TDR: 3.8 x 10^{-4} / spill (after veto:)
5.2 x 10^{-4} / spill (w/o fiducial cut)

IBD Delayed region
(hatch gamma / cosmic ray induced gamma)
TDR: 5.6 x 10^{-3} / spill (after veto:)
9.9 x 10^{-3} / spill (w/o fiducial cut, cosmic gamma)
Comparable hatch gamma (w/o any cuts)



PSD capability for fast neutron



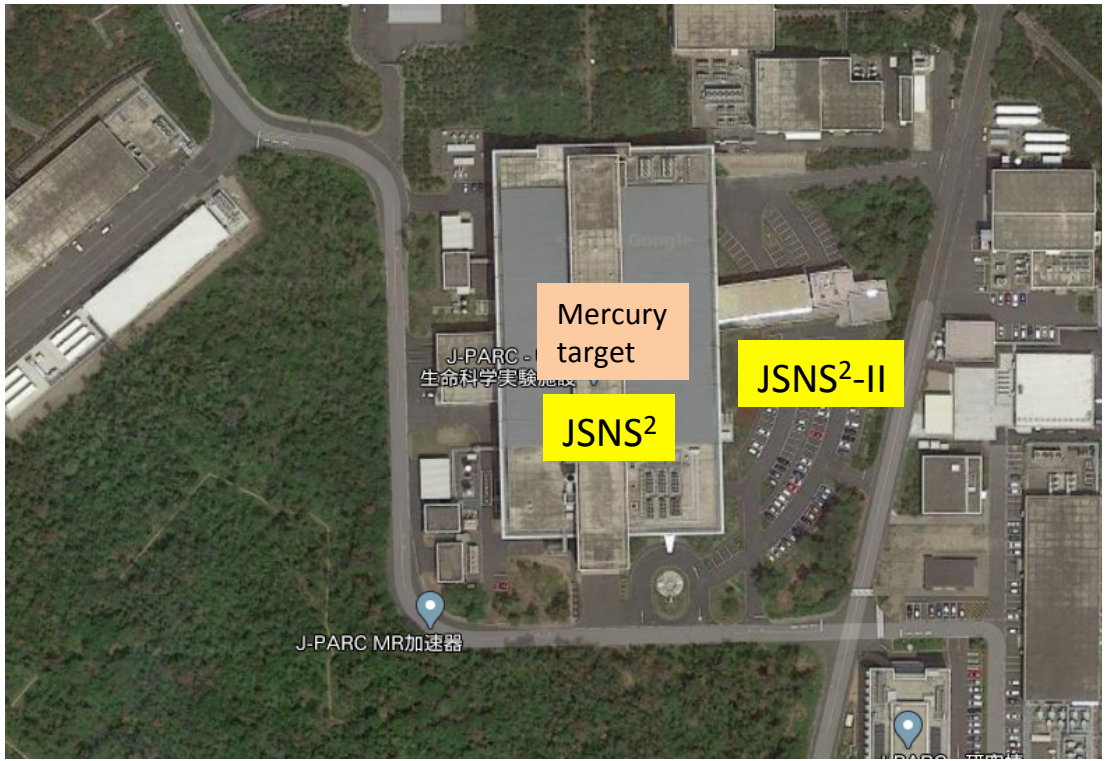
Average Waveform (with Data)

- Michel electron vs Fast neutron
- Difference of IBD prompt energy region (20 < E < 60 MeV)

The difference of dE/dx is clearly shown in the rising edge, the head, and the tail.

PSD study is on-going with both likelihood method and machine learning.

JSNS^2-II : 2nd detector location (outside of MLF)



arXiv:2012.10807

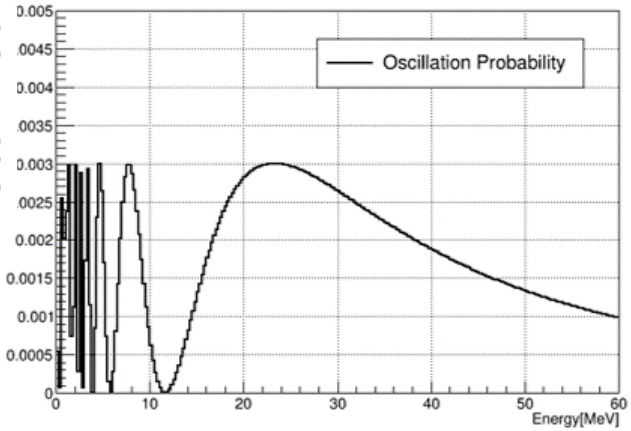
MLF approved to use 10 × 10 m space (Dec/2020).

Proposed to J-PARC PAC (Jan/2021). and stage 1 (out of 2 stages) was approved.

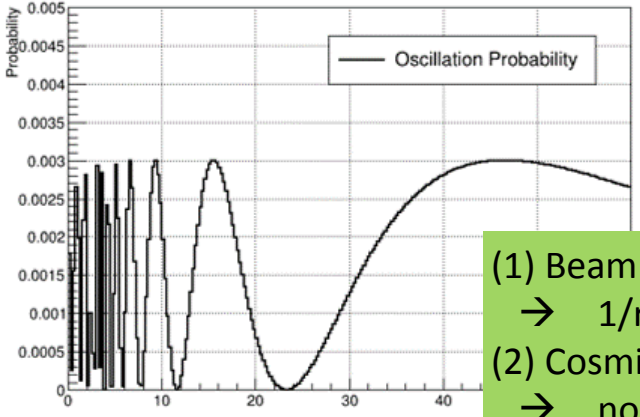
- Baseline : ~ 48 m
- Similar concept with JSNS^2.
- Twice larger target volume.
- Ground survey was done.
- **DayaBay donated GdLS(40000 L) and LS (60000 L). Ready to use (Storing in Japan now)**

Merit of the 2 detector

Ocs. Prob



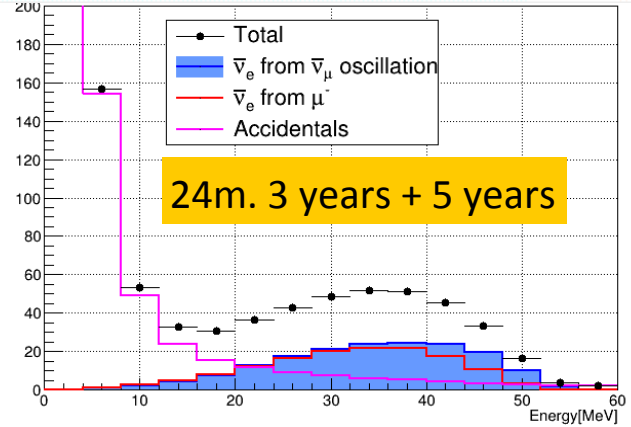
Difference in oscillation. Prob.



(1) Beam related BKG
→ $1/r^2$
(2) Cosmic ray BKG
→ no difference

<u>reduction in the syst. uncertainties also</u>

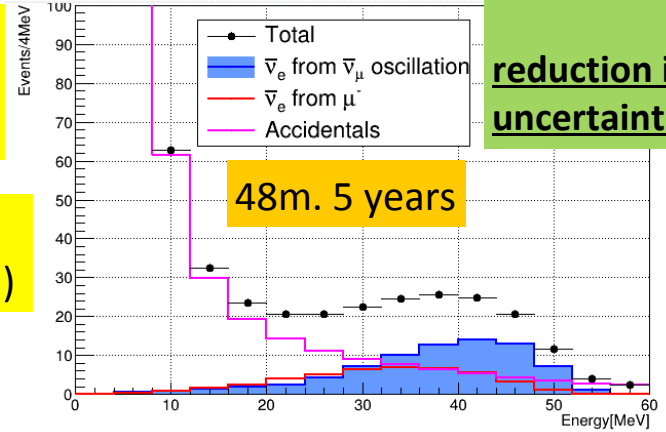
Number of events



24m. 3 years + 5 years

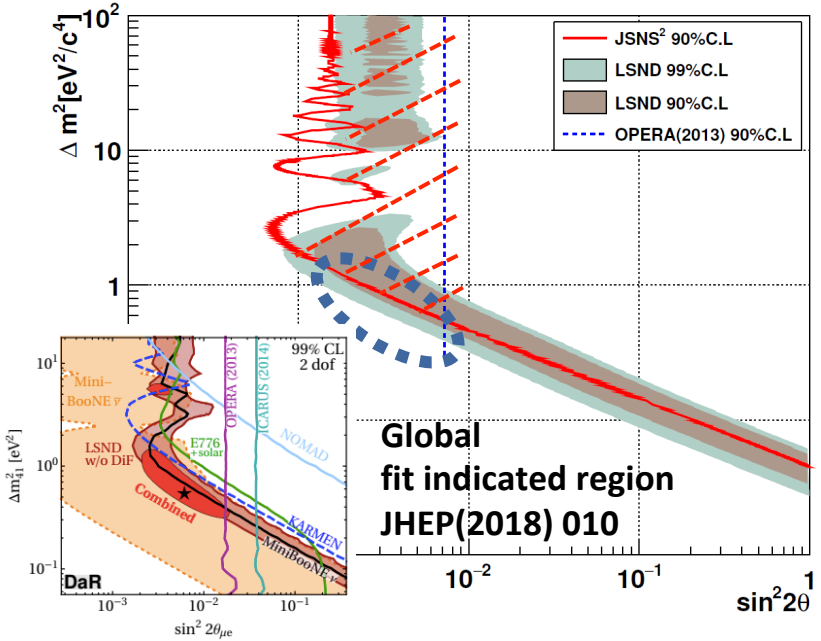
(Δm^2, $\sin^2 2\theta$)
= (1.2 eV^2, 0.003)
LSND best fit

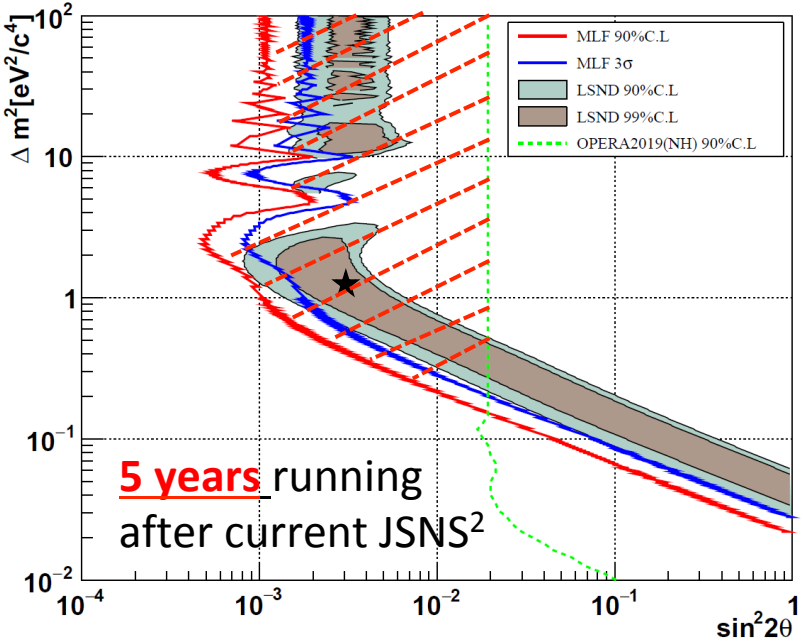
3 years (JSNS^2)
+ 5 years (JSJS^2-II)



48m. 5 years

JSNS^2-II sensitivity

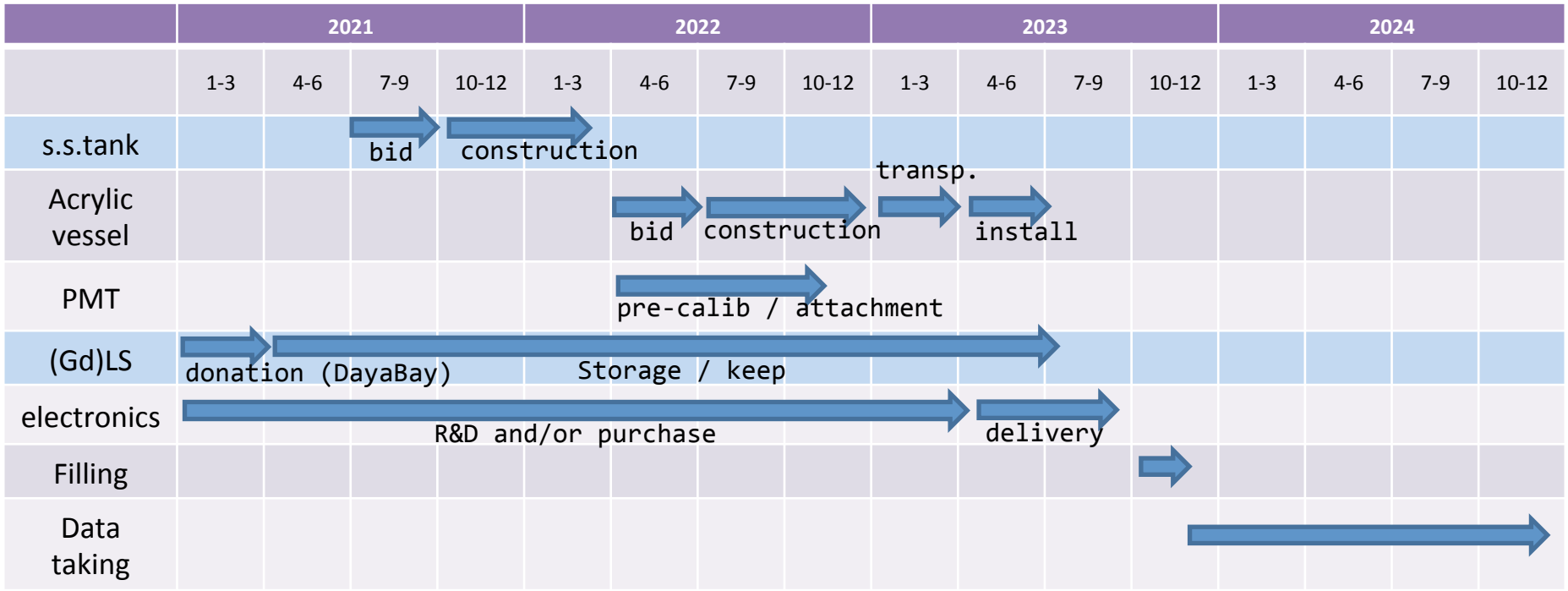




Assumed starting point of the JSNS^2-II : **after 3 years of running of the current JSNS^2 detector**

- The sensitivity becomes better, especially lower Δm^2 region
- **3sigma C.L. line covers most of LSND indicated region**
- **If we could reduce the flux uncertainty, the sensitivity would be more better.**

Timescale of JSNS^2/JSNS^2-II



Summary

- **JSNS^2 aims to test the LSND anomaly directly.**
  + Uses the same neutrino source (μ), target (H) and detection principle (IBD), but much smaller accidental background due to Gd-loaded LS and low duty factor J-PARC MLF beam.
- **First physics run (June, 2020) and second physics run (Jan - June, 2021)**
  + Preliminary numbers were almost as expected.
  + Analysis is ongoing and expecting to see interesting results soon.
- **JSNS^2-II using a new detector is newly proposed**
  + **Essential to improve the sensitivity, especially lower Δm^2 region. Grant was approved.**
  + Similar concept with the JSNS^2 detector.
  + DayaBay donated the GdLS (40,000 L)/ LS (60,000 L) for the JSNS^2-II. Thanks a lot.
  + MLF approved the space. Construction of detector vessels are being discussed with companies.
  + Aim to start from later in 2023.

Thanks for listening